National Renewable Energy Laboratory
Innovation for Our Energy Future

Western Wind and Solar Integration Study - Phase 2

Stakeholder Webinar
May 19, 2011

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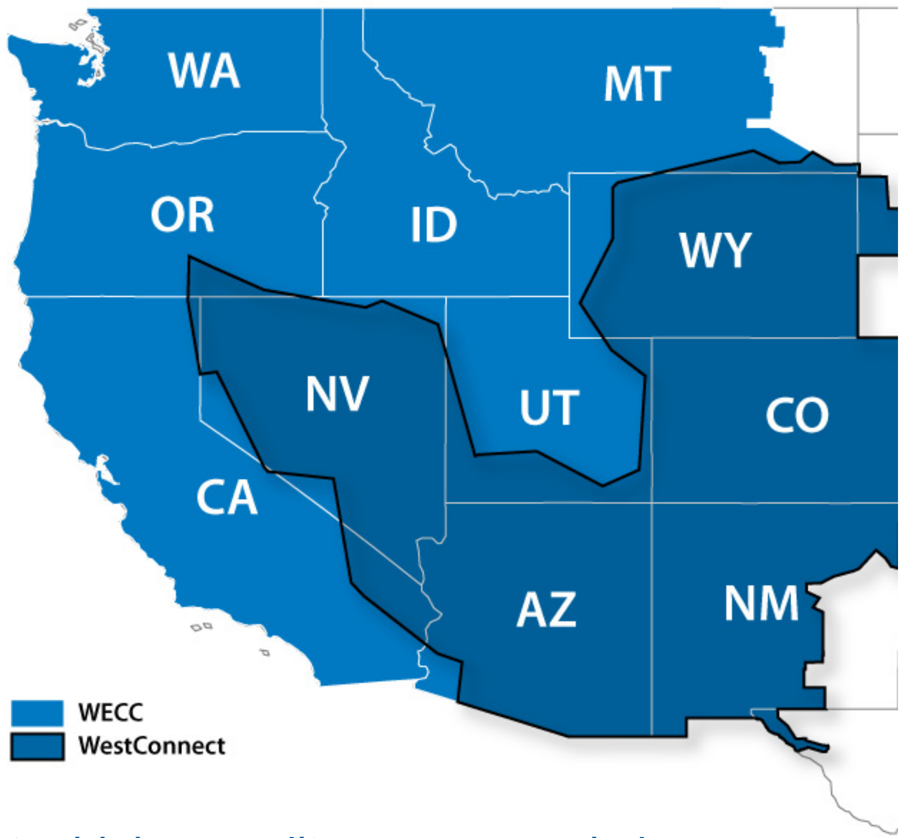
Agenda

- Phase 1 results
- Phase 2 plan
- Fossil plant cycling/ramping costs
- Emissions
- Production Simulation Modeling
- Scenarios
- Mitigation Options
- Questions

Phase 1 of WWSIS

Phase 1 - Can we integrate 35% wind and solar in the West?

Goal - To assess the operating impacts and economics of wind and solar on the WestConnect grid.



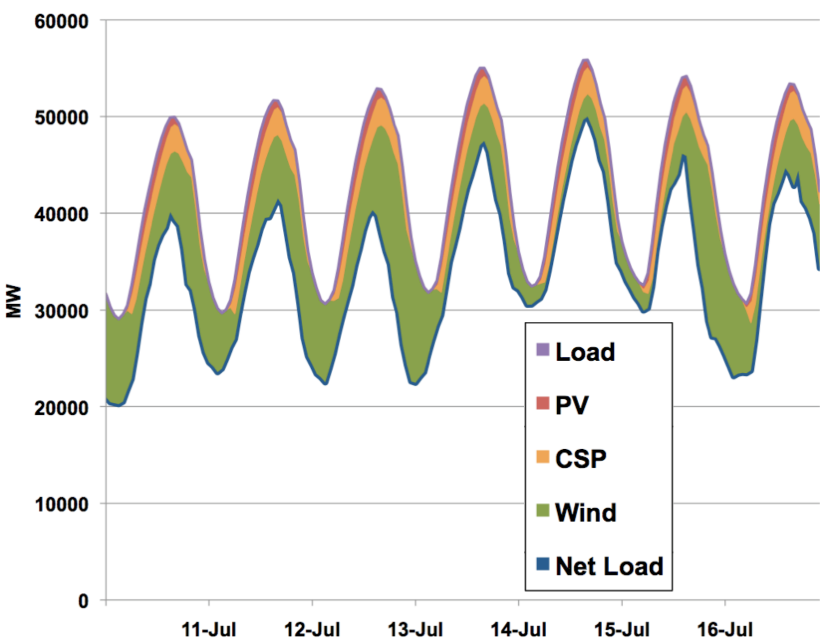
- How do local resources compare to remote, higher quality resources via long distance transmission?
- Can balancing area cooperation help manage variability?
- Do we need more reserves?
- Do we need more storage?
- How does geographic diversity help?
- What is the value of forecasting?

What did we model in Phase 1?

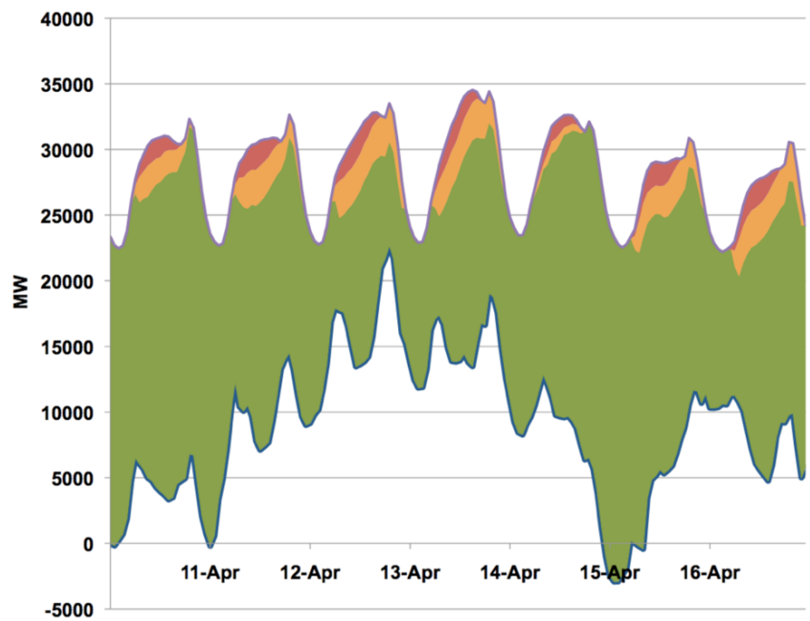
- Modeled up to 35% wind/solar in WestConnect (up to 27% in WECC)
- Modeled the year 2017 three times
- Used historical load and weather patterns from 2004, 2005, 2006 (need correlated load/wind/sun data!)
- Statistical analysis of variability. Focused on extreme events.
- Power simulations of all of WECC on hourly basis and down to 1 minute for extreme events.
- Developed high resolution (in time and space) wind and solar data

How did the system operate in the high renewables case?

Mid-July



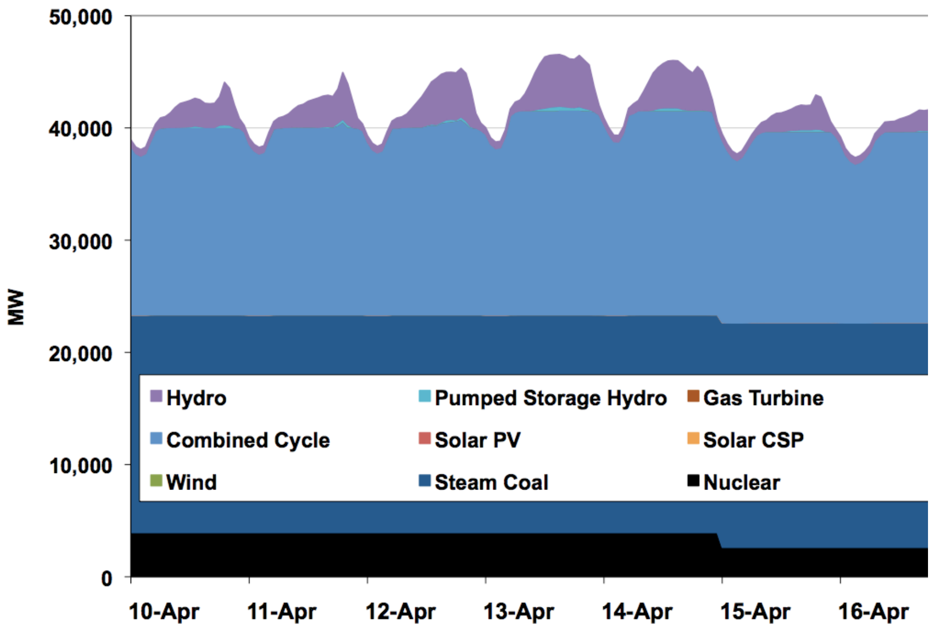
Mid-April



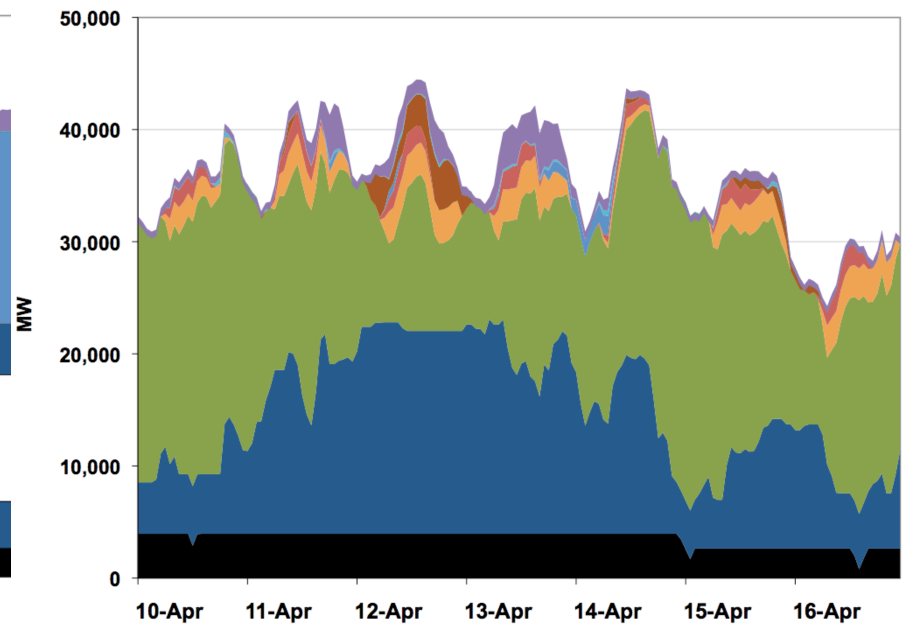
Mid-April shows the challenges of operating the grid with 35% wind and solar. This was the worst week of the 3 years studied.

Operations during mid-April

No Wind/Solar

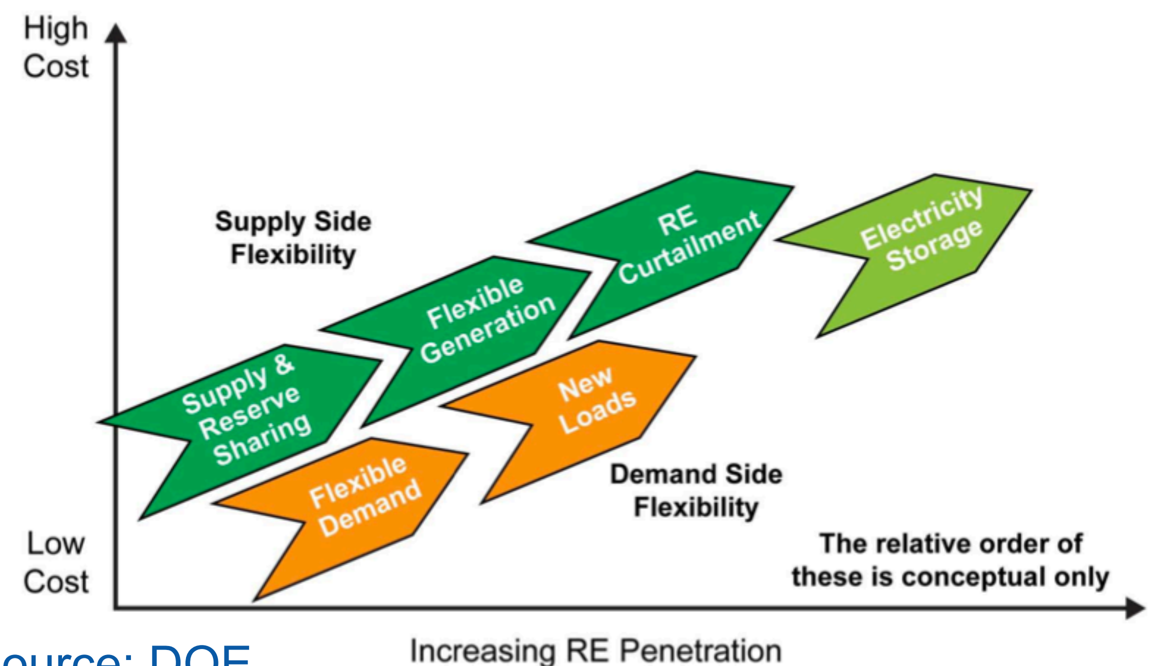


High renewables case



Phase 1 found: It is operationally feasible for WestConnect to accommodate 30% wind and 5% solar if:

- Substantially increase balancing area cooperation
- Increase use of subhourly scheduling
- Increase utilization of transmission.
- Enable coordinated commitment and dispatch over wider regions.
- Use forecasts in operations.
- Increase flexibility of dispatchable generation.
- Commit additional operating reserves as appropriate.
- Implement/expand demand response programs.
- Require wind to provide down reserves.



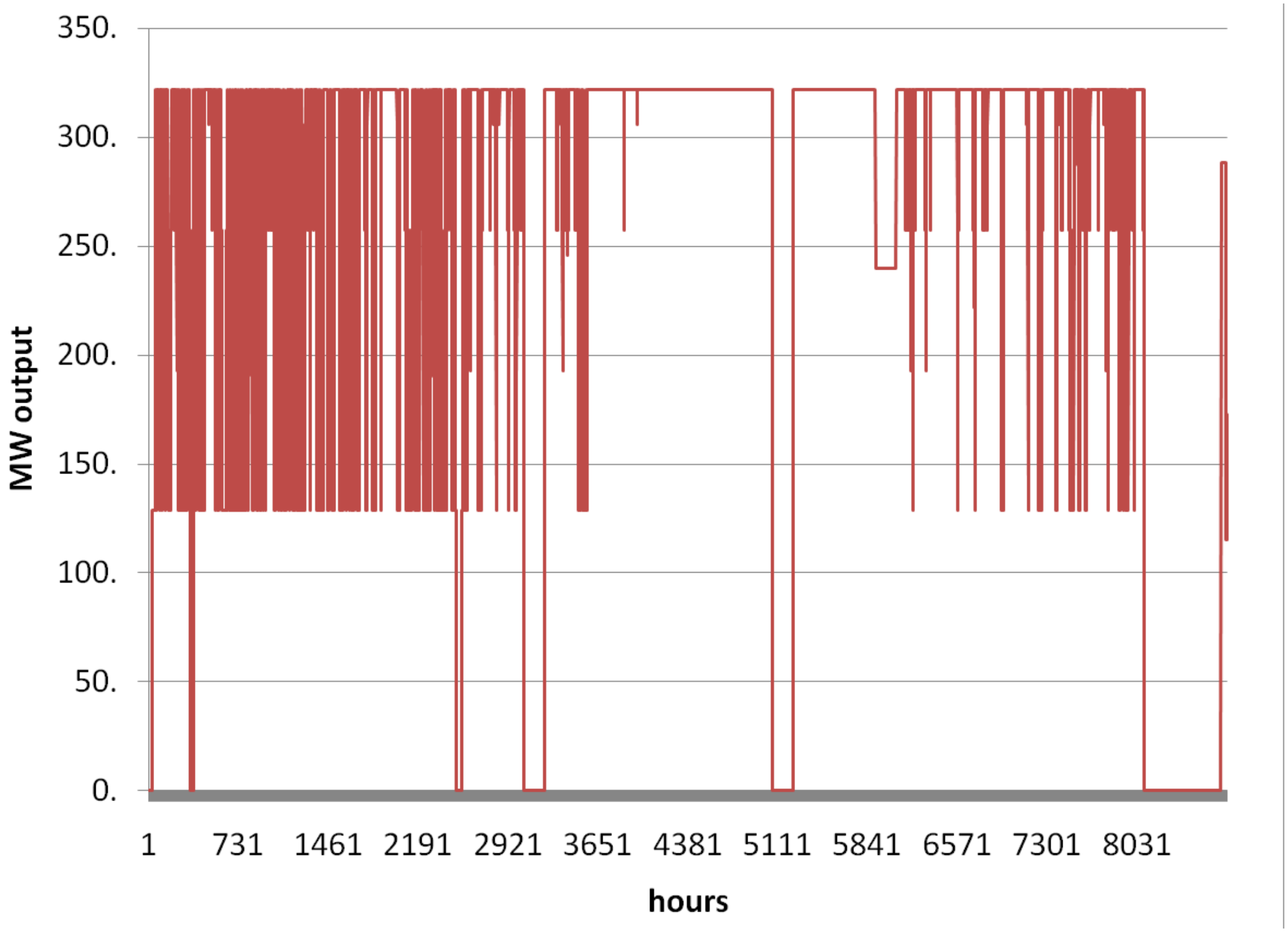
Source: DOE

Phase 2 of WWSIS

WestConnect input on Phase 2

- Increased cycling and ramping of fossil assets will increase O&M expenses. Obtain these costs and include them in modeling.
- Increased cycling and load following of fossil assets causes units to operate at suboptimal emissions conditions. Capture non-linear relationship between emissions and generation level especially when cycling/ramping. Increase accuracy of emissions analysis.
- Review cycling implications on fossil assets associated with sub-hourly scheduling. Characterize impact including shutdowns, frequency of increased cycling. How will planning for maintenance outages change?
- More accurate characterization of non-renewable generation portfolio (min gen, startup time, ramp rate, etc).

Can the fossil fleet do this?

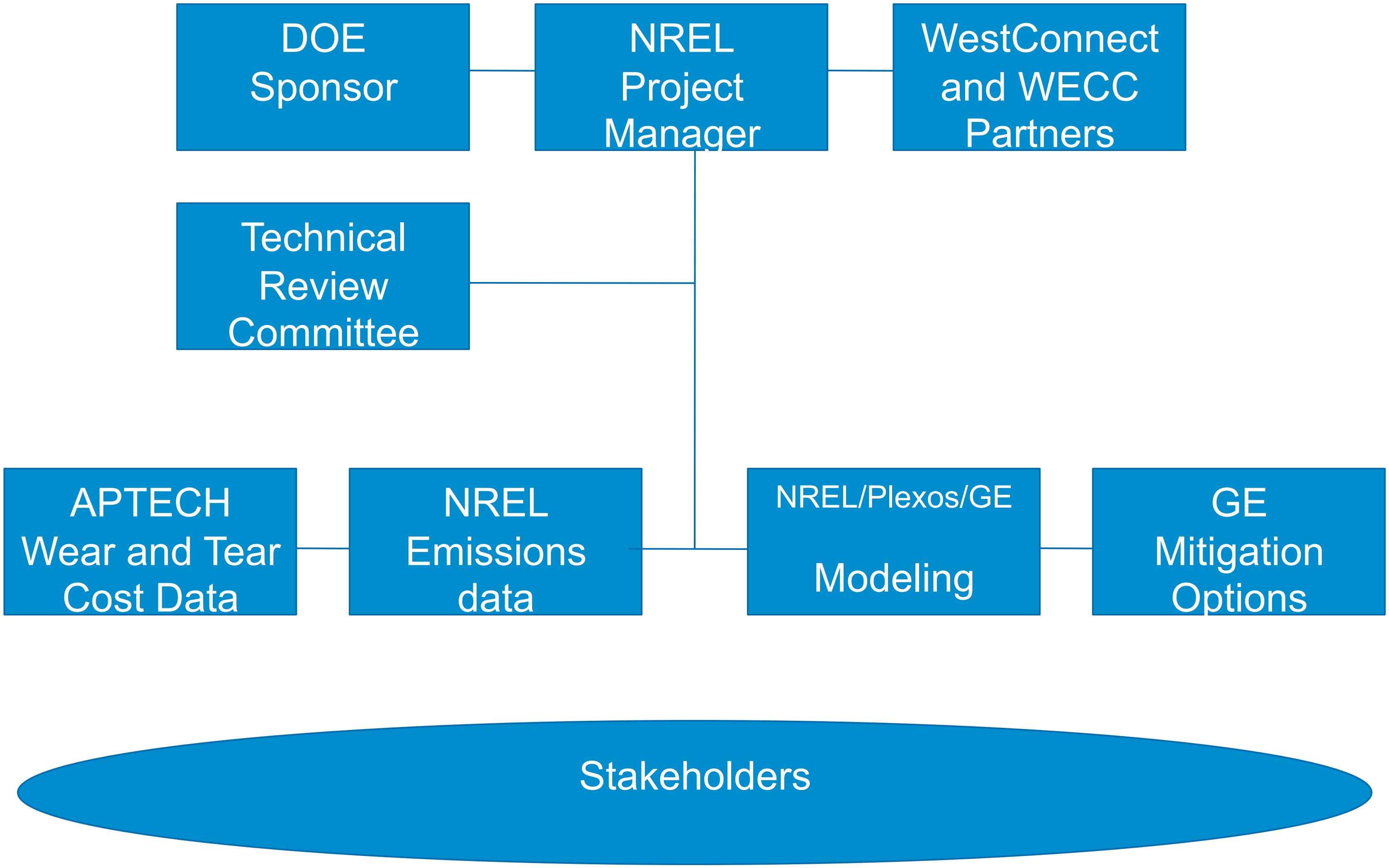


WWSIS Phase 2

Goal – Examine in greater detail and with higher fidelity, the impacts of wind and solar on thermal generation and potential mitigation options

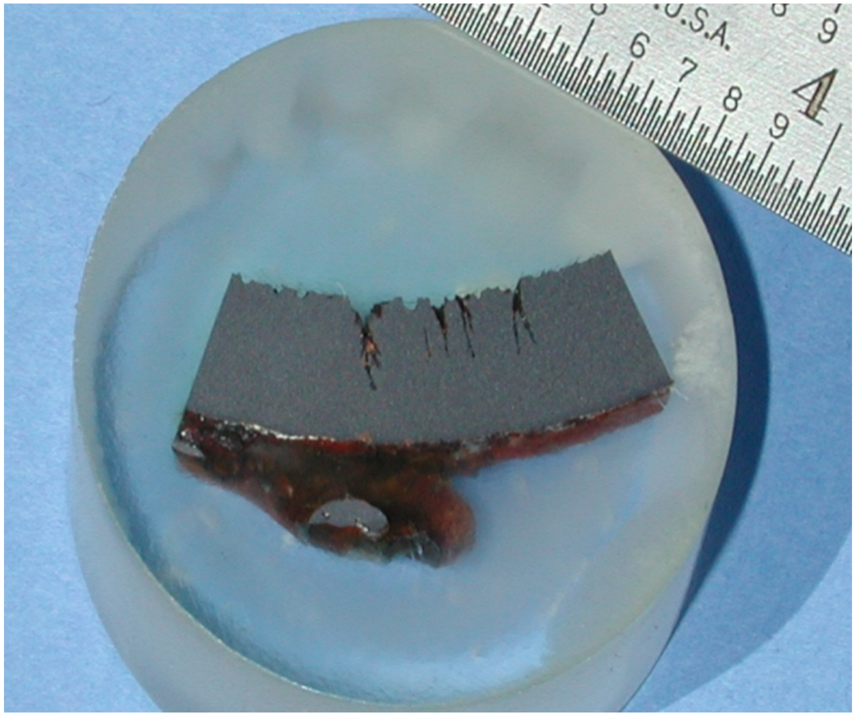
1. Obtain better data for wear and tear costs of thermal units during cycling and ramping
2. Examine emission impacts of thermal generation cycling and ramping in greater detail
3. Optimize unit commitment and economic dispatch with these inputs and examine impact of increasing penetrations of wind and solar on thermal units
4. Examine mitigation options to reduce costs of thermal unit cycling and ramping

Team


DOE
Sponsor
NREL
Project
Manager
WestConnect
and WECC
Partners
Technical
Review
Committee
APTECH
Wear and Tear
Cost Data
NREL
Emissions
data
NREL/Plexos/GE
Modeling
GE
Mitigation
Options
Stakeholders

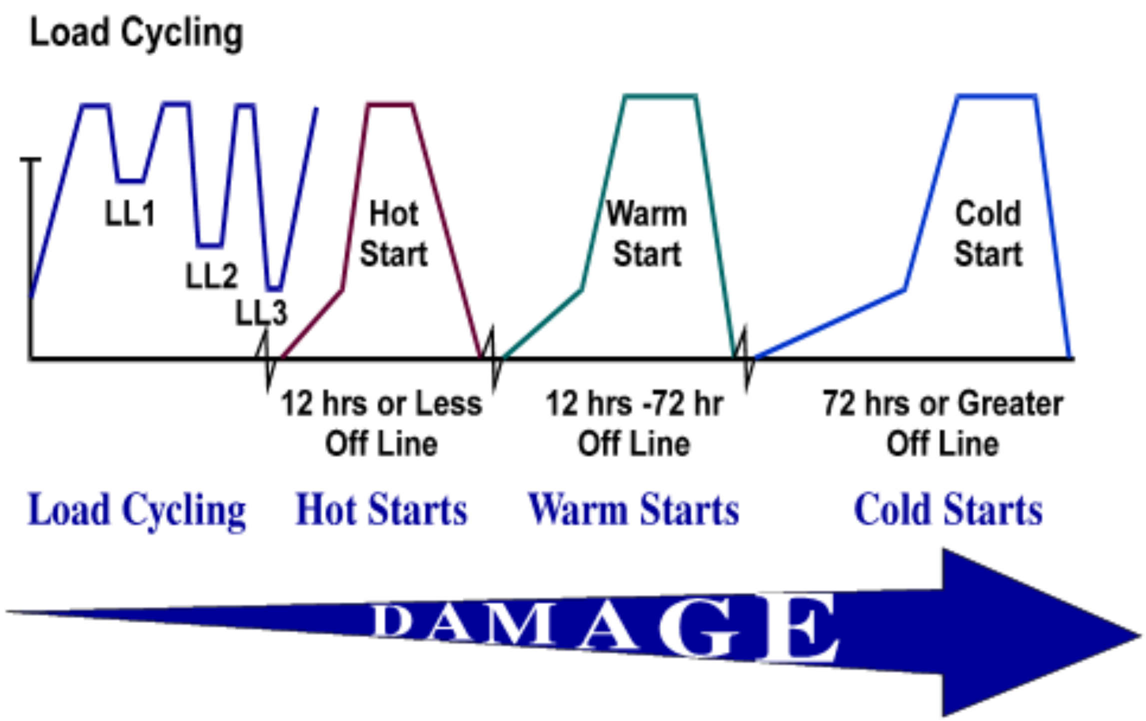
Wear and Tear Costs of Thermal Plant Cycling and Ramping

Boiler Corrosion Fatigue



Source: Steve Lefton, Intertek APTECH, with permission.

Generation Unit Cycling Definitions



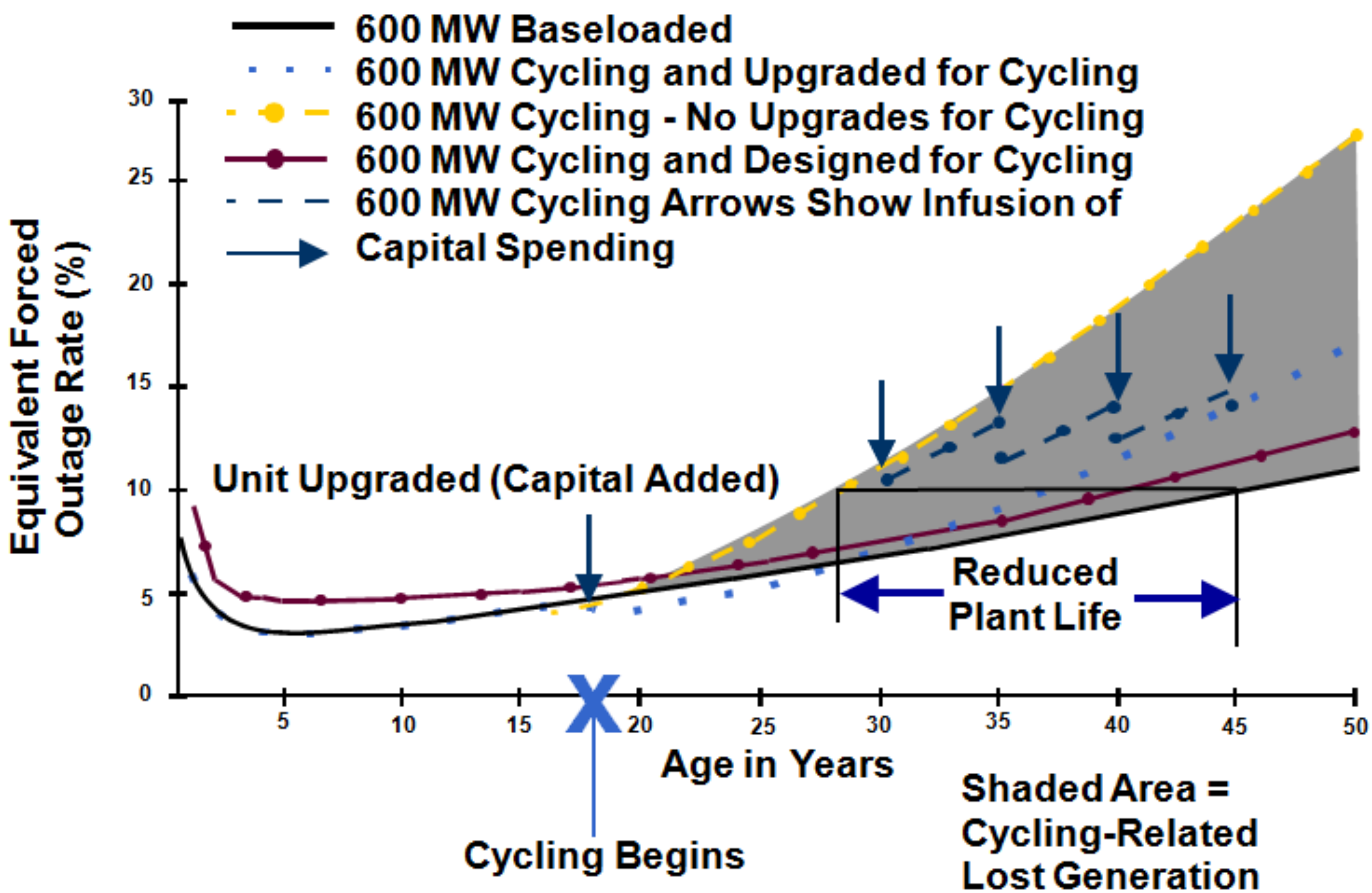
EHS

Load Cycling

- LL1: Lowest Load at Which Design Temperatures can be maintained
- LL2: Current “Advertised” Low Load
- LL3: Lowest Load at Which the Unit can Remain On-Line

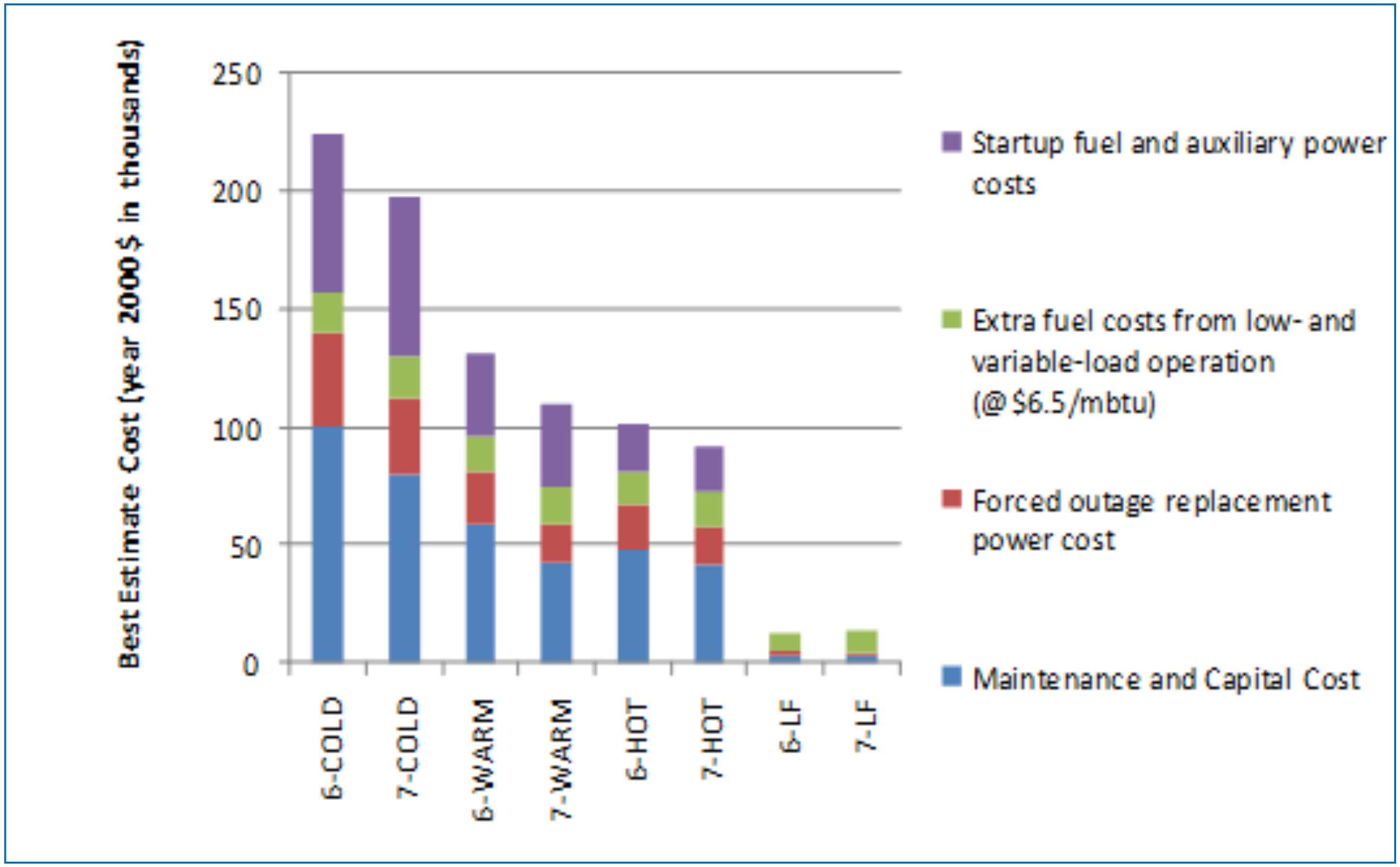
Source: Steve Lefton, Intertek APTECH, with permission.

Cycling Effects



Source: Steve Lefton, Intertek APTECH, with permission.

Typical Cycling Cost Breakdown for Two Large Units



Source: Steve Lefton, Intertek APTECH, with permission.

Wear and Tear Cost Data

- Intertek APTECH has analyzed some 400 thermal units to determine wear and tear costs due to ramping and cycling. They have also developed a Cycling Advisor model to optimize commitment and dispatch of thermal generation with these costs taken into account.
- Split fossil plants into 7 categories by size and type.
- Costs to include upper and lower bound for:
  - Hot, warm, and cold start;
  - Cost for normal ramp rate from min. to max. and for fast ramp rate;
  - Cost for different min output levels.
- Forced outage rates as a function of cycling/ramping
- Only lower bound costs will be made public
- WECC is cost-sharing this data
- Apply cost data to WWSIS-1 results to determine 'ceiling' on costs.

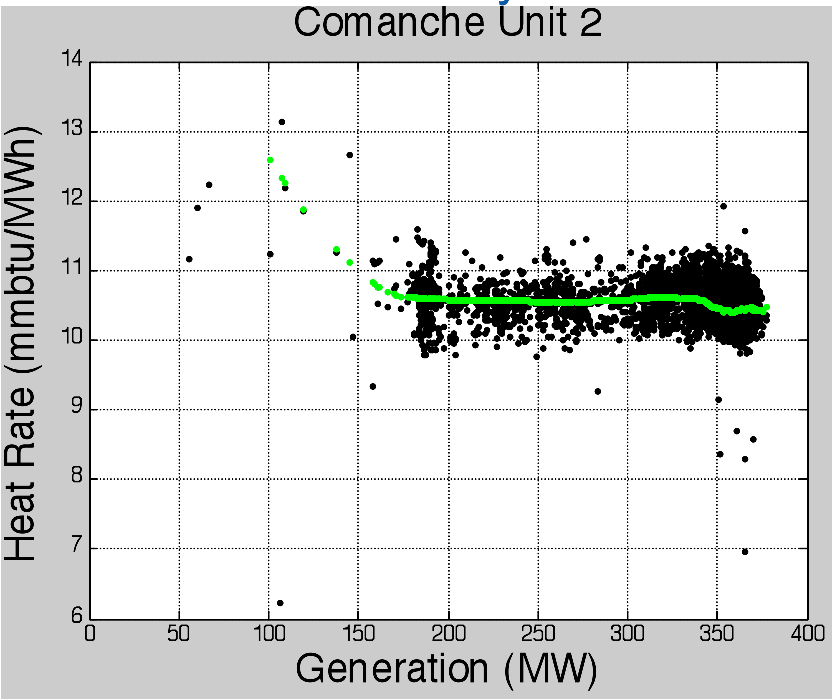
Emissions Analysis

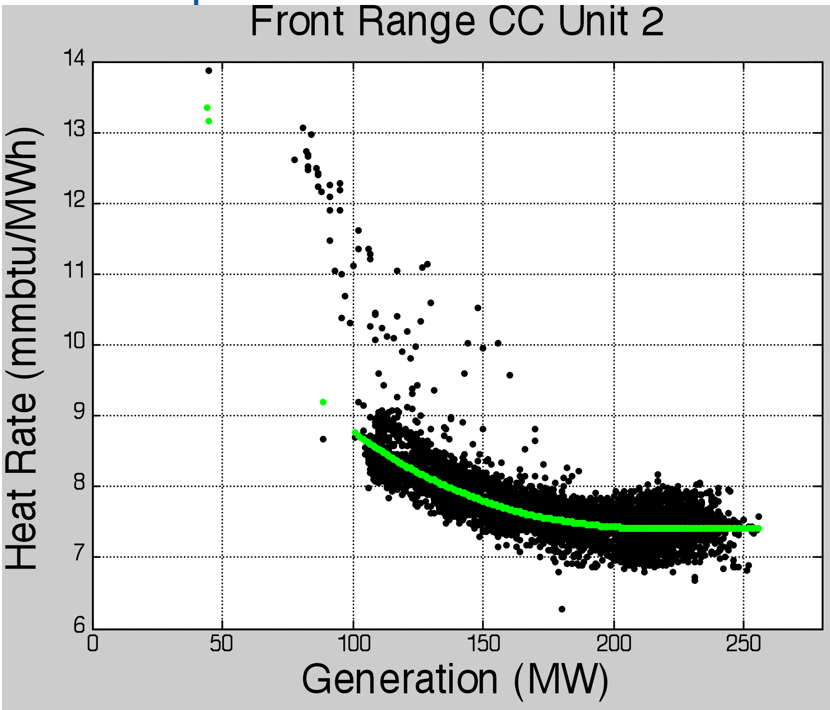
Emissions

- Refine emissions rates data including emissions at part-load, emissions during up-ramps and down-ramps.
- Use EPA Continuous Emissions Monitoring dataset (2008 is latest QA'd/QC'd dataset) to capture for each plant in WECC:
  - CO_2, NO_x, SO_x emissions rates for each plant at different load levels.
  - CO_2, NO_x, SO_x emissions rates as a function of startup and ramping

Heat Rate and Emission Curves

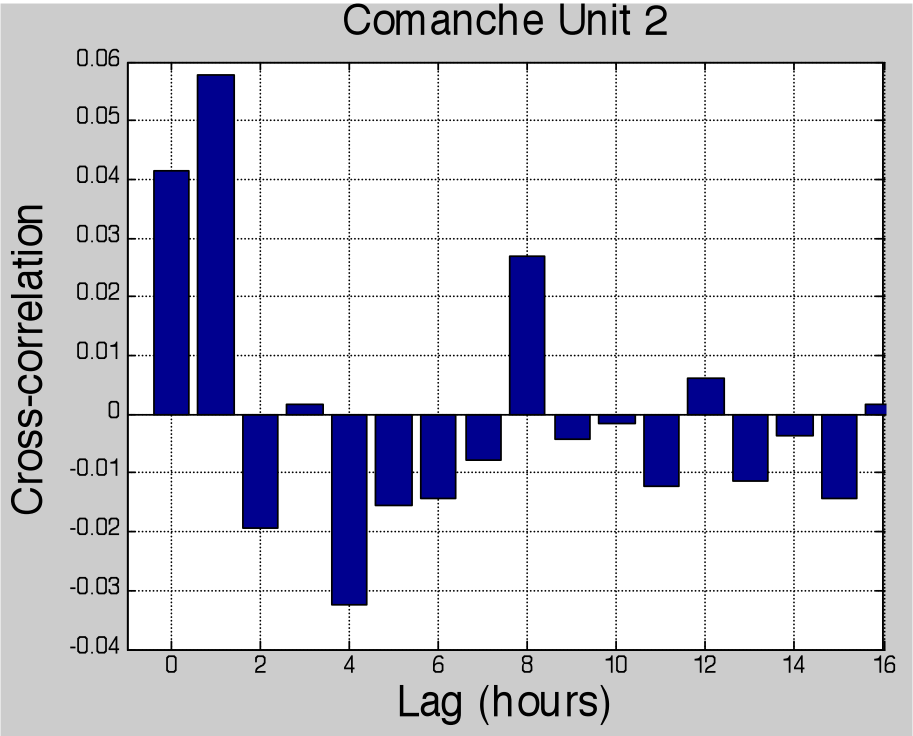
- Local linear fit for every unit.
- Compile emissions at full load and 50% of full load.
- Residuals used for subsequent analysis.
- Eliminate units with obviously clustered data, caused by:
  - Installation of pollution control equipment during year;
  - Part-time operation of pollution control equipment;
  - Combined cycle units in various modes of operation.

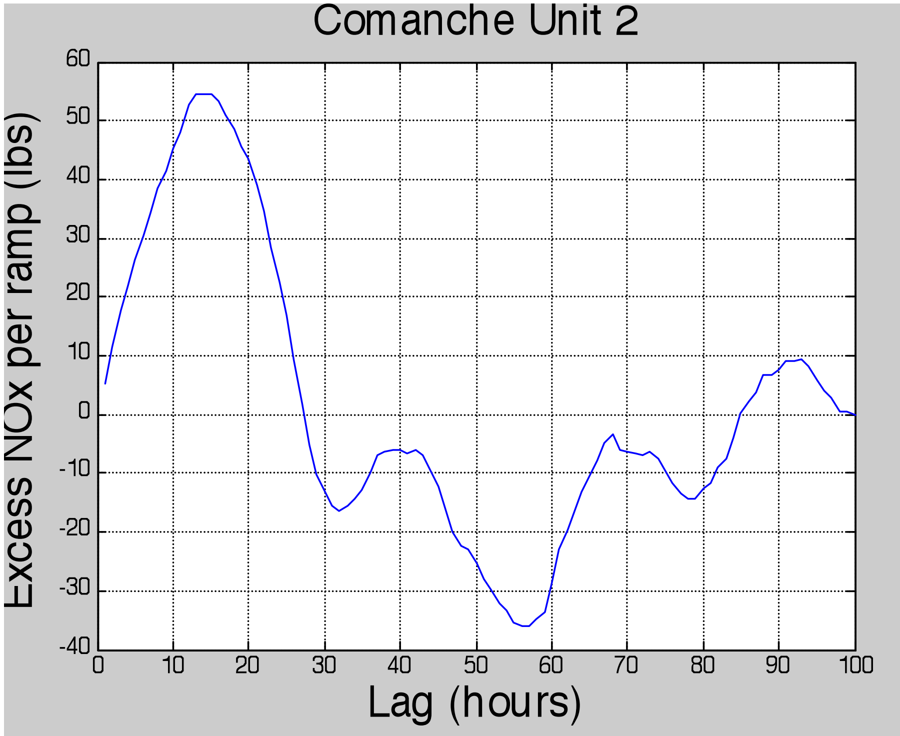




Time-Lagged Pollution Control Failures?

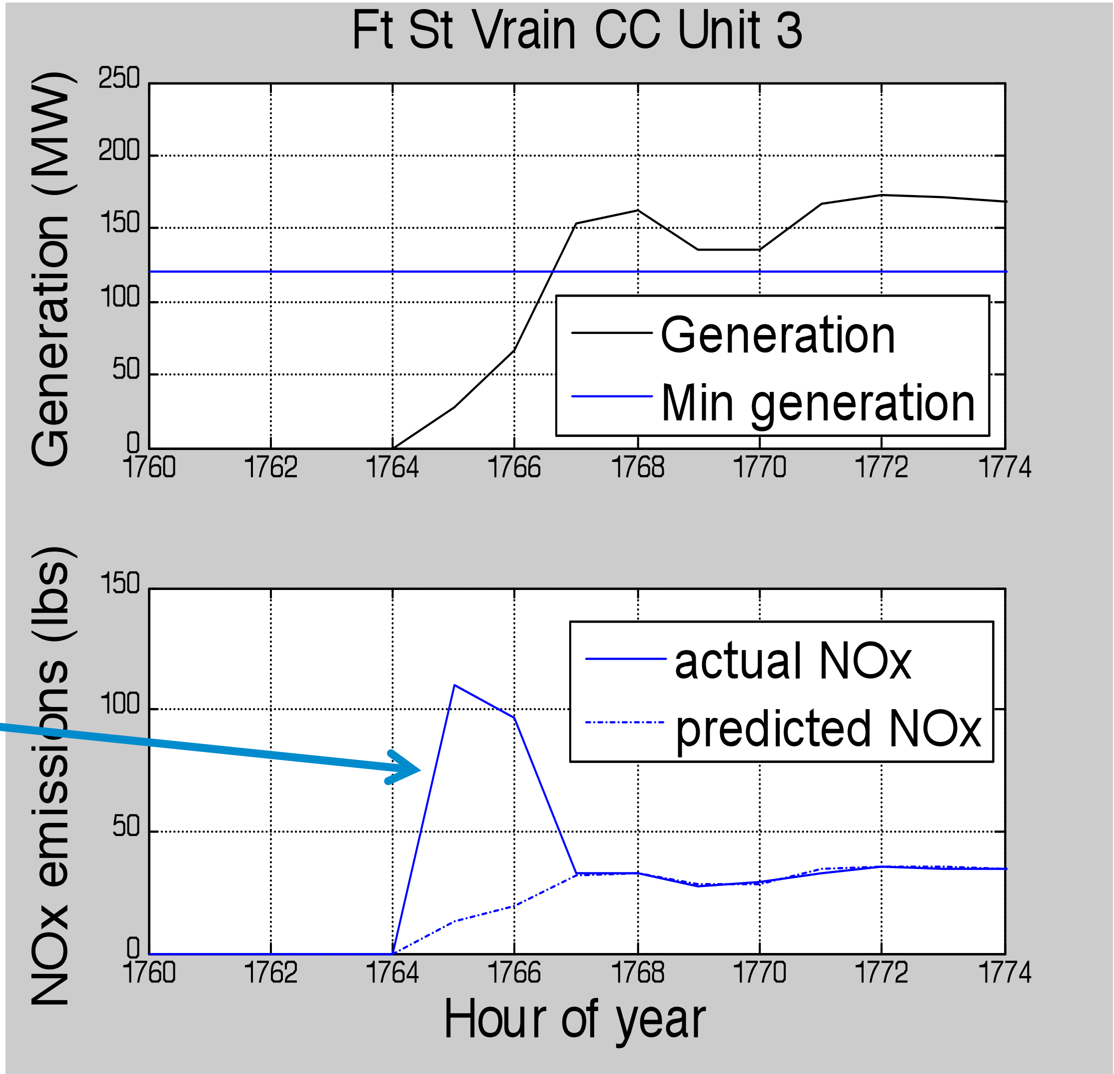
- Lagged cross-correlation between unit ramp rate and the change in emission residuals (see figure on left) –
  - Should identify if pollution control problems are impacted by ramping.
- If evidence of a correlation exists, sum the residuals for all hours impacted by ramping (within 10 hours of a 5% hourly ramp) and average to determine excess emissions caused by ramping (see figure on right).





Startup Emissions

- Add up residuals from all hours prior to and following a startup until unit reaches its minimum generation level.
- Integral between the predicted and actual NO_x curves.



Results (explanation)

All results are generation-weighted averages by type.

Part-load penalty:

- Percentage increase in emissions (lbs) per unit of generation (MWh) when the unit is operating at 50% of maximum generation (compared to maximum generation).

Ramping penalty:

- Ratio of the increased emissions due to a 5% hourly ramp to the emissions from the unit during one hour of full-load operation.

Startup penalty:

- Ratio of the increased emissions due to a startup to the emissions from the unit during one hour of full-load operation.

Results (heat input or CO_2)

Unit type	Part-load penalty	Ramping penalty	Startup penalty
Coal	5.1%	0.4%	110%
Gas CC	15.6%	0.3%	32%
Gas CT	12.4%	0.3%	32%

Results (NO_x,SO_2)

Unit type	Part-load penalty	Ramping penalty	Startup penalty
Coal (NO_x)	1.2%	2.8%	290%
Gas CC	30%**	0.7%	950%**
Gas CT	19%	0.8%	670%**
Coal (SO_2)	5.4%	13.4%	270%

**These numbers are highly sensitive to input assumptions (percent loading) and/or a small number of extreme outliers (some are bad fits).

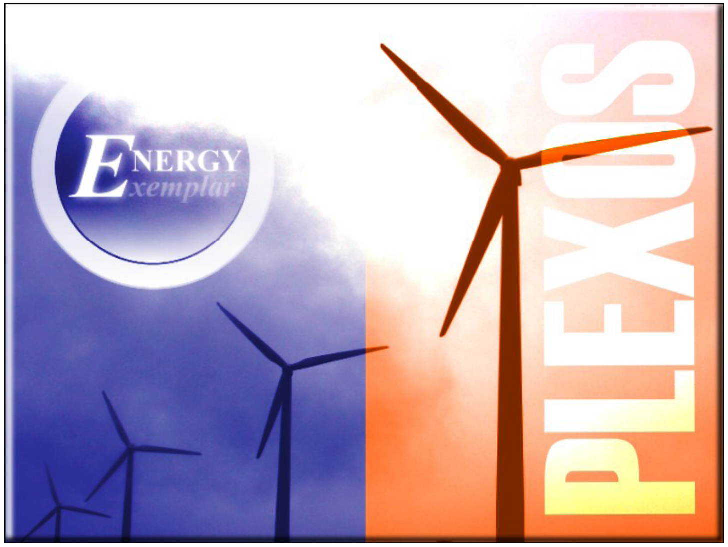
Production Simulation Modeling

PLEXOS Overview

- MIP formulation allows the addition of constraints on generator operating regions
  - Can then explicitly model times when cycling occurs
  - Can easily incorporate cycling and ramping costs
  - Can consider these costs when making unit commitment and dispatch decisions
- Easily switches between explicit transmission modeling and zonal modeling
  - Can focus on certain regions to examine interesting areas more closely
- Allows dispatch at five minute time steps
  - Can easily examine interesting events in further detail

PLEXOS – Renewable Integration Studies

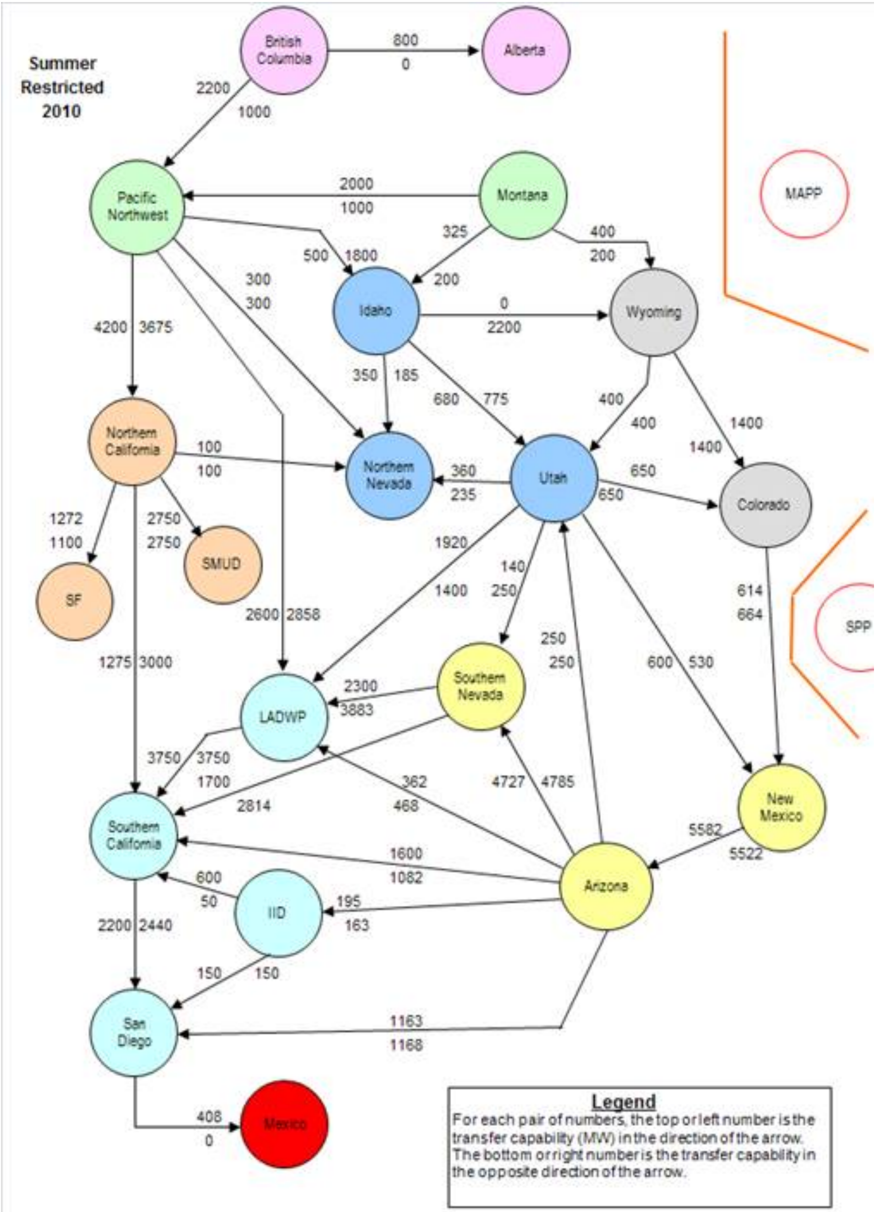
- CAISO 20% Study
- CAISO 33% Study
- MISO Wind Integration Study



Plexos Modeling of WECC

- As with WWSIS1, model all of WECC because renewables in WECC impact WestConnect
- Benchmark Plexos model with WECC TEPPC 2020 model
- Build scenarios
  - Opportunity to build more realistic base scenario
  - Include centralized PV
  - Incorporate new wear and tear cost data and new plant-specific emissions data
  - Can examine impact of wind versus solar on the grid

Transmission zones



- Run zonally initially. Nodal runs at a later date for deeper dives.
- Will use these 20 TEPPC zones. Aiming at more rather than less zones to better approximate actual current operations.
- Commit and dispatch within each zone with hurdle rates between zones to allow for interzone transfers.

Scenarios

Scenarios

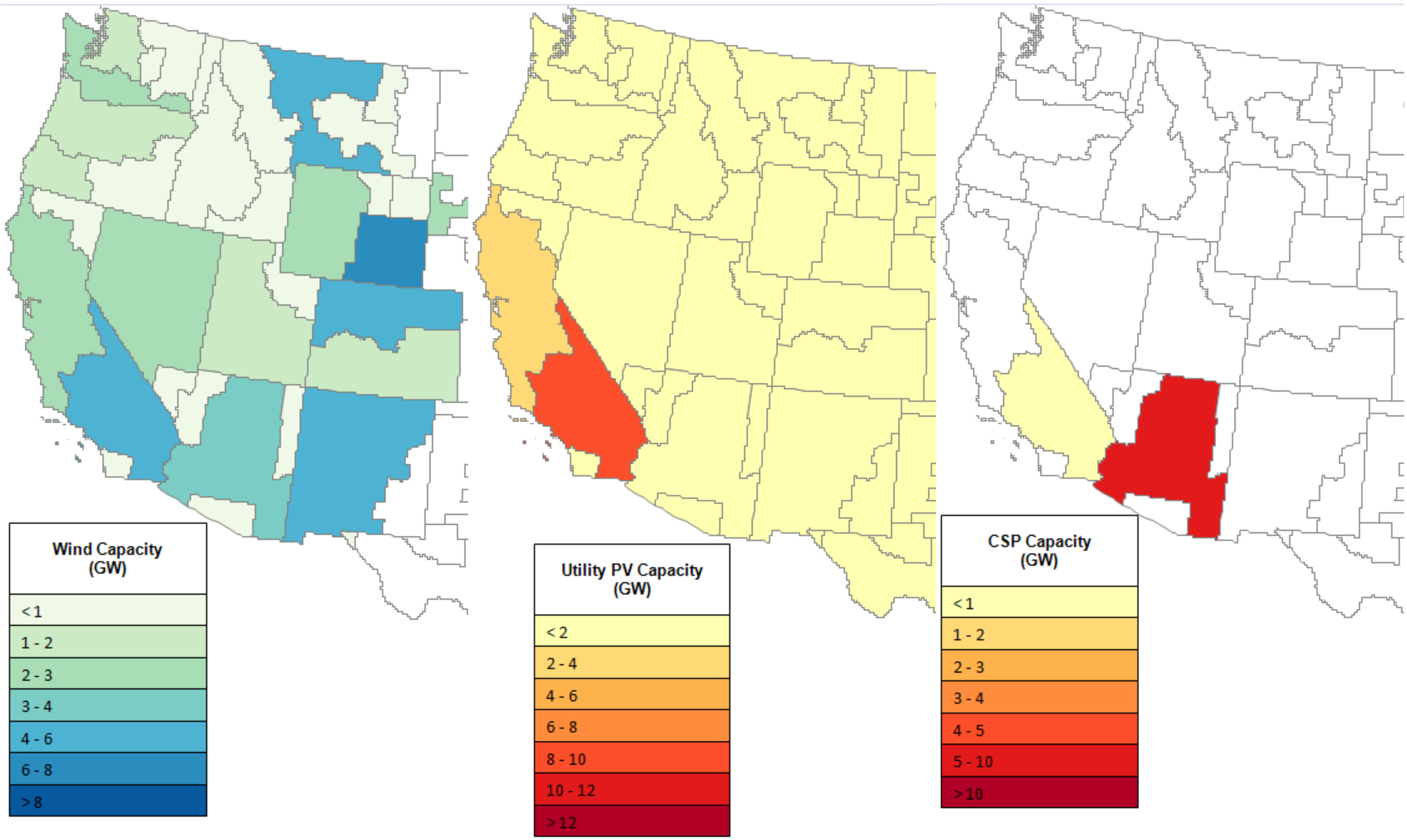
Penetration by Energy	High Wind	Intermediate	High Solar
11%	WECC TEPPC 2020 8% wind 3% solar		
22%			
33%	25% wind 8% solar	16.5% wind 16.5% solar	8% wind 25% solar

Use NREL ReEDS model to expand generation fleet subject to geographical and electric power system constraints (and select regional distribution)

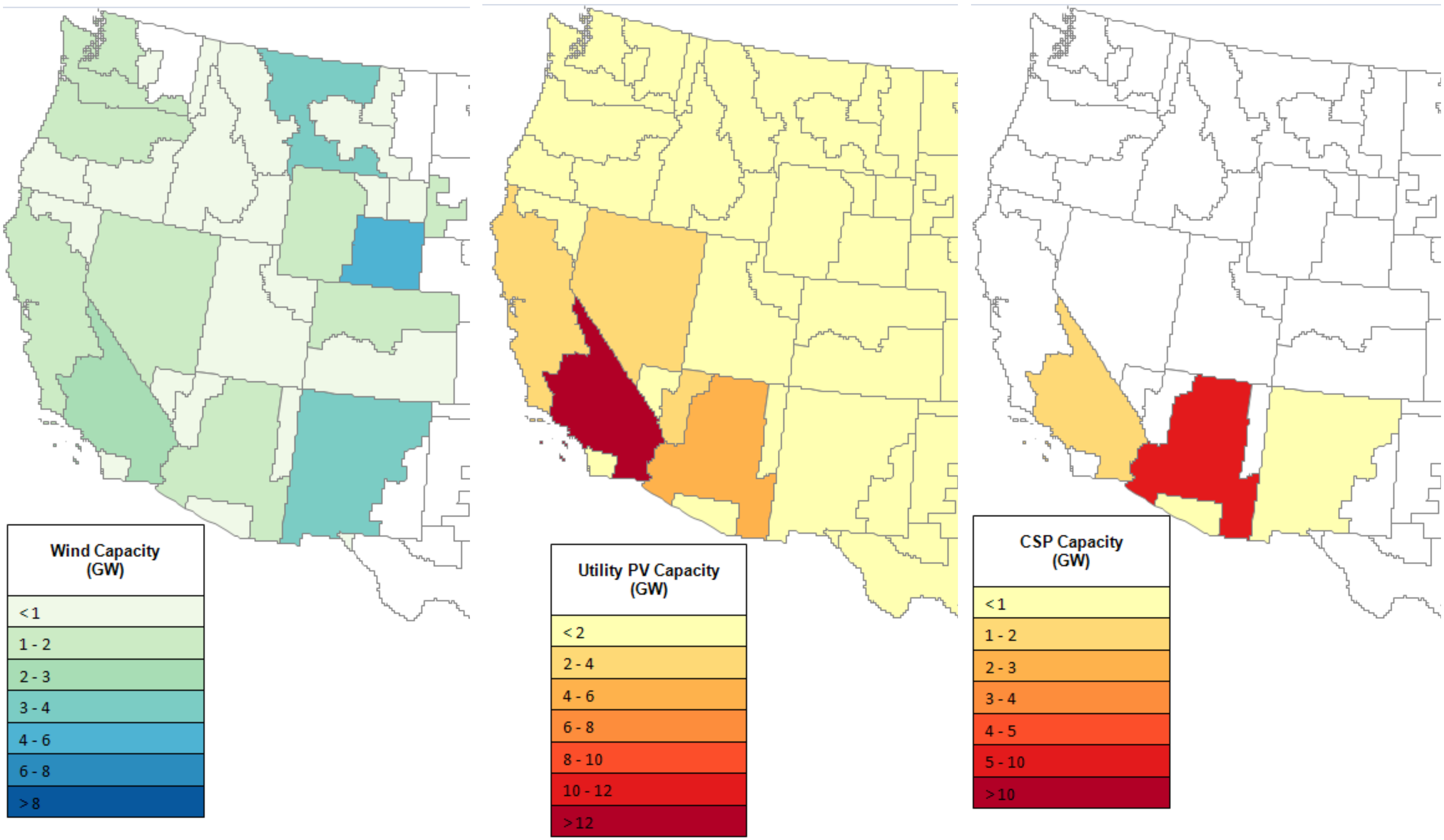
Solar consists of 40% CSP and 60% PV
CSP has 6 hours of storage

*note that related side sensitivity analyses in FY12 may include Plexos runs of various penetrations of solar with various PV/CSP ratios

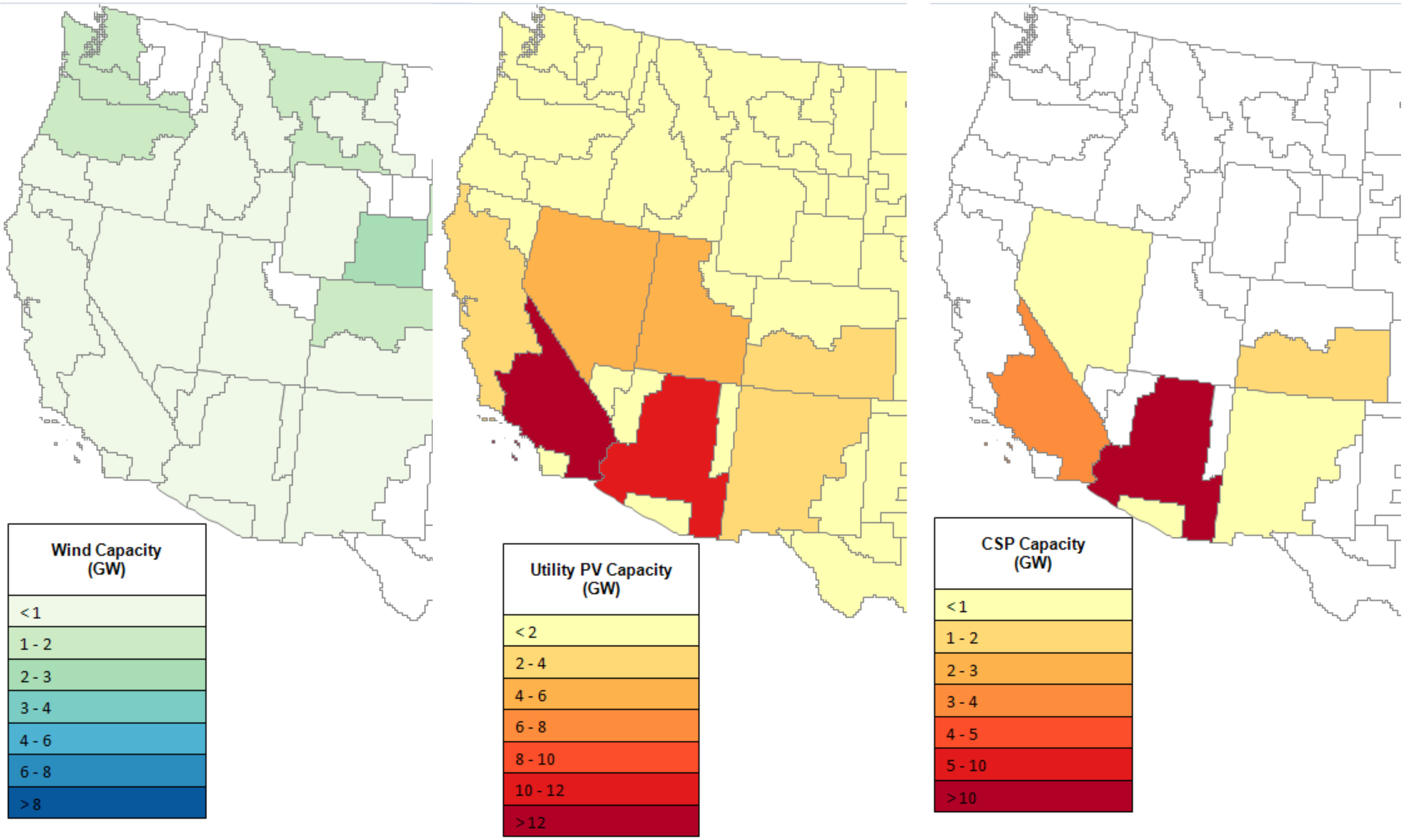
High wind (25% wind, 4.8% PV, 3.2% CSP)



Intermediate (16.5% wind, 9.9% PV, 6.6% CSP)



High solar (8% wind, 15% PV, 10% CSP)



Scenario Development Tasks

- Select locations of wind and solar sites based on capacity factor and proximity to transmission
- Map sites to high voltage buses
- Run unconstrained and constrained transmission cases in Plexos
- Develop transmission expansion plan to accommodate 33% wind/solar
- Run a final iteration in Plexos to determine if transmission expansion is adequate

Data Refinements

Wind/solar data refinements

- Potential refinements to wind dataset to eliminate seams from modeling process and ensure that forecast error distributions match measured forecast error distributions
- Refinements to PV dataset to model utility-scale PV of several sizes (100, 300, 500 MW). WWSIS1 modeled only rooftop DG PV.

Retirement Scenarios

- Other analysis shows plant retirements to have significant impact on cycling/ramping costs
- WECC TEPPC DWG retirements are based on CAISO 33% study

Mitigation Options

Mitigation Options

- Work with GE power plant experts on emissions, combined cycle, steam turbines.
- Examine initial modeling results:
  - What are the parameters that have the biggest impact on production cost? Mingen, downtime, ramp rates;
  - What are the impacts that are most important to mitigate? Efficiency, emissions, equipment lifetime.
- Propose and rank mitigation options:
  - E.g., Cycling specific coal units off in spring, upgrade units to better cycle/ramp.
- When does it make sense to upgrade a unit and what kind of upgrades are needed?

Other mitigation options that may be examined:

- Increase thermal energy storage in CSP plants to 10 hours
- Run high penetration of PHEV/EV’s

Proposed Schedule

- May – July 2011
  - Aptech – Cost data
  - NREL – Emissions data
  - NREL – refine wind/solar datasets
  - NREL – site wind/solar plants for scenarios
  - NREL/Plexos/GE – set up and benchmark models
  - GE – Run “ceiling” scenario with cost data
  - TRC Meeting to review scenarios and data inputs
- Jul – Sep 2011
  - NREL/GE – transmission expansion – copper sheet analysis
  - TRC Meeting to review transmission plans

Proposed Schedule

- Sep – Summer 2012
  - NREL/Plexos/GE – Run scenarios, sensitivities
  - GE – Review preliminary results and develop mitigation options
  - Run mitigation options
  - TRC Meeting to review preliminary results
- Jun – Sep 2012
  - Develop draft report
  - Hold stakeholder meeting to review draft results
  - Final report

For further questions/comments:

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Extra slides

Background: WWSIS Phase 1 Modeling

- Production simulation was conducted with GE MAPS
- WECC represented as 14 transmission zones
- 5 balancing areas
- Hourly simulation over three years
- Used 2008 Ventyx database
- WECC database - with updates - used for transmission